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MIXER NOZZLE-EXTERNALLY BLOWN FLAP NOISE TESTS

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INTRODUCTION

This report summarizes the preliminary experimental results of the noise suppression capability of a mixer type nozzle used with a model of the externally blown flap (EBF) lift augmentation system. The EBF is one of the systems proposed for use with STOL aircraft. Previous results with conventional nozzles (ref. 1) show that the jet exhaust-deflected flap interaction noise must be suppressed to meet STOL aircraft noise goals (95 EPNdB at 152.4 meters).

A mixer type nozzle consists of an array of multi-element flow passages rather than a single nozzle with one large flow passage. The purpose of the mixer nozzle is to cause rapid decay of the jet exhaust velocity by mixing with the surrounding air prior to the flap station so that the noise generated by the jet impinging on the flap surfaces is reduced to acceptable levels.

An experimental program to evaluate mixer nozzle effectiveness is being conducted at the Lewis Research Center (e.g., ref. 2). The particular nozzle configuration employed in the noise tests of this report was judged to be the most suitable at the time the work reported herein was undertaken. Small scale EBF noise tests with a multi-element orifice, grossly similar to the final configuration (ref. 3) showed a reduction in

noise level when compared to the results of a single orifice of the same area and operating at the same conditions. Therefore, a large scale model that more closely simulated a real nozzle was fabricated and tested.

This report presents the experimental noise measurements that were obtained from the large scale mixer nozzle and EBF model. The data were obtained over a range of nozzle exhaust velocities (172 to 284 meters/sec) and flap angles. Comparisons are made between the results of the mixer nozzle and those obtained with a standard single convergent nozzle.

APPARATUS

The air flow system with the wing and mixer nozzle in place is shown in figure 1. The system is the same as the one used for the results reported in reference 1. Pressure upstream of the nozzle was set by adjustment of the flow control valve which was supplied with cold air (280 K - 300 K) from the Center's air supply system. An orifice flowmeter was located upstream of the control valve. Total pressure and temperature were measured at the nozzle inlet. Mufflers installed in the regions indicated in figure 1 helped suppress internal noise generation. The wing was mounted on the stand so that the spanwise direction was vertical. The nozzle axis was 3.91 meters above grade and was located 1.52 meters from the bottom of the wing and 1.22 meters from the top.

The test configuration of the externally blown flap model and mixer nozzle is shown in figure 2. The wing section with the flaps retracted, had a chord length of 2.08 meters, and a span of 2.74 meters. The flaps could be placed in three positions relative to the wing chord line;

(1) leading flap 30°, trailing flap 60°, (2) leading flap 10°, trailing flap 20°, and (3) zero angle (flaps retracted). The wing chord line was at a 5 degree angle of attack relative to the nozzle centerline.

The position of the mixer nozzle relative to the wing is shown in the sectional view in figure 2. The nozzle initially consisted of 4 straight lobes and 4 lobes that were canted 10° outward from the nozzle centerline. The canted lobes promoted the velocity degradation (ref. 2).

Initially, the nozzle was operated as an eight-lobe nozzle (all lobes open) and oriented so that a straight lobe was closest to the underside of the wing. However, preliminary tests with this configuration and the wing flaps in the 30°-60° position showed that only a slight reduction in flap interaction noise was achieved, compared to flaps blown by a standard single convergent nozzle. It was found that intense wing scrubbing occurred as a result of the air jet from the closest lobe being located so near the wing. Therefore, the distance from the wing to the nearest lobe was increased by rotating the nozzle and blocking one canted lobe as shown in figure 2.

Figure 3 is a photograph of the test facility with the wing flaps in the 10°-20° position. Figure 4 shows the configuration and dimensions of the mixer nozzle. The exit area of the nozzle lobes was reduced by about 20 percent from the upstream portion of the lobe. The total exit area of the seven lobed mixer nozzle was 1255 cm^2. An elliptical centerbody was placed upstream of the lobes to improve the flow coefficient of the nozzle. A comparison of actual flow rate to ideal flow rate showed that the ratio was about .99.

Free stream velocities with the wing removed were calculated from total pressures measured downstream of the nozzle. The total pressure surveys were made across two diametrically opposed straight lobes and also two opposing canted lobes. The velocities were calculated by assuming that the total temperature at the probe was the same as the measured temperature upstream of the nozzle. Also, the static pressure at the probe was assumed to be atmospheric pressure.

Sound data were taken for the nozzle alone and with the wing in place. Twenty 1.27 cm diameter condenser microphones were placed at various intervals on a 15.24 meters radius circle around the wing-nozzle setup. The center of the microphone circle was located on the nozzle centerline halfway between the nozzle exit and the intersection with the 60° flap. The microphone circle was in a horizontal plane 3.91 meters above an asphalt surface and perpendicular to the vertically mounted wing.

Sideline noise measurements were made with the mixer nozzle and the flaps in the 30°-60° position. This was done by suspending a microphone 15.24 meters above the center of the microphone circle from the boom of a mobile crane. For these tests only two microphones were placed on the standard microphone circle, one at 85° and one at 275° from the air supply line.

Noise data were analyzed by a 1/3-octave band spectrum analyzer. The analyzer determined sound pressure level (SPL) spectra referenced to 2×10^{-5} N/m^2. Overall sound pressure levels (OASPL) were computed from the SPL data.

RESULTS

Peak Velocity Degradation

Velocity profiles across the straight lobes of the mixer nozzle are shown in figure 5. The measurements were made without the wing at an axial distance of 183 cm downstream of the nozzle exit. This distance is that from the nozzle exit to the impingement point on the 60 degree flap, measured along the axis of the nozzle, when the wing is in place. With the wing in place, the left side of the figure would be the side nearest the wing. As shown in figure 5, the jet is still in the development stage since the flow characteristics of each element is easily identified. In addition, the profile is seen to be asymmetric about the nozzle centerline as a result of the asymmetry of the 7-lobe nozzle configuration.

Results of the velocity decay measurements for the mixer nozzle are summarized in figure 6. The local peak axial velocity, V, used as part of the ordinate in figure 6, is for a straight lobe. (At a given axial distance, the straight-lobe peak velocity was greater than the peak velocity from a canted lobe.) The value of the abscissa was based on the total equivalent diameter (D_{et}) of the exit area of the nozzle. For the nozzle of this test the total equivalent diameter was 40 cm. The curve in figure 6 is representative of the velocity decay results obtained with circular single element nozzles (ref. 2). Data for a 33 cm diameter convergent nozzle (ref. 1) and a 6.1 cm diameter orifice (ref. 3) are presented for comparison. As shown in the figure the mixer nozzle performed as expected by giving a faster rate of velocity decay than a single nozzle.

Sound Measurements

Nozzle alone. - Results of the sound measurements for the mixer nozzle alone are shown in figure 7. In figure 7(a) the variation in overall sound pressure level (OASPL) directivity is shown at a radius of 15.24 meters at various nozzle pressure ratios. The directivity is symmetrical about the nozzle centerline with the peak OASPL occurring at 135°. A decrease in the level occurs as the exhaust velocity decreases. In figure 7(b) the sound pressure level (SPL) 1/3 octave spectra is shown at 85° from the air supply line for a nozzle pressure ratio of 1.7 and 1.3. The spectra are broadband with a rapid rate of decrease in SPL above 10 kHz. Figure 7(c) shows a comparison of the spectra for the two nozzle pressure ratios at the peak OASPL position, 135° from the air supply line. Again, the spectra are broadband but, compared to the 85° position, have a higher SPL up to a frequency of 10 kHz. Above 10 kHz the data at the two angular positions are similar.

Comparison of the noise data for the mixer nozzle alone and a standard single convergent nozzle alone is shown in figure 8. The standard nozzle data were obtained at Lewis (ref. 1) for a nozzle with a 33 cm diameter exit and then scaled up to the mixer nozzle size. The method of scaling is given in reference 1. Figure 8(a) shows that the mixer nozzle has a 1 to 2 dB higher noise level than the standard nozzle at nearly all angular positions for both nozzle pressure ratios. In figure 8(b) the SPL 1/3 octave spectra for the nozzles are compared at 85°. As shown, the mixer nozzle contains higher levels of high frequency noise which is characteristic of multi-element nozzles.

Nozzle with wing. - Noise data for the mixer nozzle with the wing in place and the flaps at the 30°-60° position are shown in figure 9. The OASPL directivity plot at a radius of 15.24 meters, figure 9(a), shows that the noise level is greatest below and forward of the wing (0°-105°). The SPL 1/3 octave spectra at 85°, figure 9(b), peak at a frequency between 200 and 400 Hz depending on the pressure ratio (or exhaust velocity).

A direct comparison of the noise data for the mixer nozzle with the 30°-60° flaps and the mixer nozzle alone is shown in figure 10. The OASPL between 0 and 105 degrees is much greater with the wing in place than with the nozzle alone. This is a result of the additional noise generated by the impingement of the jet on the wing-flap system. The results are similar for the other nozzle pressure ratios.

The noise data for the mixer nozzle and the flaps in the 10°-20° position are shown in figure 11. Again, the OASPL is greater below and forward of the wing, but the level is not as great for a given pressure ratio as when the flaps were in the 30°-60° position. The SPL spectra, figure 11(b), again show a peak between 200 and 400 Hz depending on pressure ratio.

A summary of the noise radiation patterns at 15.24 meters for the various wing flap positions, as well as the nozzle alone, is shown in figure 12. The data are for a pressure ratio of 1.7 only. The other pressure ratios yield similar directivity patterns, but with different levels. As shown in the figure, greater separation of the levels for the four configurations occurs below and forward of the wing, with the 30°-60° flap position being the noisiest. In the other directions the separation of the levels is not as pronounced.

A comparison of the noise data at 15.24 meters for the mixer nozzle with the 30°-60° flaps and a 33 cm single convergent nozzle with the 30°-60° flaps scaled to the mixer nozzle size is shown in figure 13. The OASPL for the single nozzle is seen to be greater than that with the mixer nozzle at all angles from the engine inlet. The same comparison with the flaps in the 10°-20° and zero position is shown in figures 14 and 15, respectively. Very little difference in the level occurs below and forward of the wing for either the mixer nozzle or the single convergent nozzle for either flap position.

Sideline noise. - The results of the sideline noise tests, with the flaps in the 30 -60 position, are shown as SPL 1/3 octave spectra in figure 16 and are compared with the spectra below the wing at 85° from the engine inlet. The OASPL for both locations are also given. For both nozzle pressure ratios the levels below the wing are higher than those at the sideline. The OASPL at the sideline is 5 to 6 dB lower than the OASPL below the wing.

Perceived noise level for the wing with the mixer nozzle and standard nozzle. - A comparison of the perceived noise level (PNL) directivity pattern at 152.4 meters for the mixer nozzle with the 30°-60° flaps and the scaled-up 33 cm diameter convergent nozzle with the 30°-60° flaps is shown in figure 17. The PNL for the flaps blown by the single convergent nozzle is higher at all angles. With the wing flaps in the 10°-20° position, figure 18, the results show that the PNL with the mixer nozzle varies from slightly higher to slightly lower below and forward of the wing. Figure 19

shows the PNL comparison for the wing with the zero (retracted) flap position. The PNL with the mixer nozzle is higher than with the single convergent nozzle (2 to 3 PNdB) for all positions below and forward of the wing.

SUMMARY OF RESULTS

The results of the noise tests with a specific configuration of a mixer-type nozzle blowing on the wing flaps of an EBF lift augmentation system can be summarized as follows:

1. With the wing flaps set in the 30°-60° position, the noise level is lower (about 6 dB) with the mixer nozzle blowing on the flaps than with a single convergent nozzle blowing on the flaps.

2. With the wing flaps in the 10°-20° setting, there is little difference in the noise level below the wing when either the mixer nozzle or the single nozzle is used.

3. With the wing flaps retracted, the noise level below the wing is higher (1 to 2 dB) when the mixer nozzle is used than when the single nozzle is used.

4. The sideline noise level with the mixer nozzle blowing on the 30°-60° flaps is lower than the noise level below the wing (5 to 6 dB).

SYMBOL LIST

C_e	nozzle (orifice) discharge coefficient
D_{et}	equivalent diameter $= \sqrt{\frac{4\,(\text{Total Area})}{\pi}}$, cm
M_j	Mach number at nozzle (orifice) exit plane
OASPL	overall sound pressure level referenced to 2×10^{-5} N/m^2, dB
PNL	perceived noise level, PNdB
SPL	sound pressure level referenced to 2×10^{-5} N/m^2, dB
V	free stream peak jet velocity, m/sec
V_j	peak velocity at nozzle (orifice) exit plane, m/sec
X	axial distance from nozzle (orifice) exit plane, m

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2. Groesbeck, D., Huff, R., von Glahn, U., "Peak Axial-Velocity Decay With Mixer-Type Exhaust Nozzles," TMX-67934, 1971, NASA, Cleveland, Ohio.
3. Goodykoontz, J. H., Olsen, W. A., Dorsch, R. G., "Preliminary Tests of the Mixer Nozzle Concept for Reducing Blown Flap Noise," TMX-67938, 1971, NASA, Cleveland, Ohio.

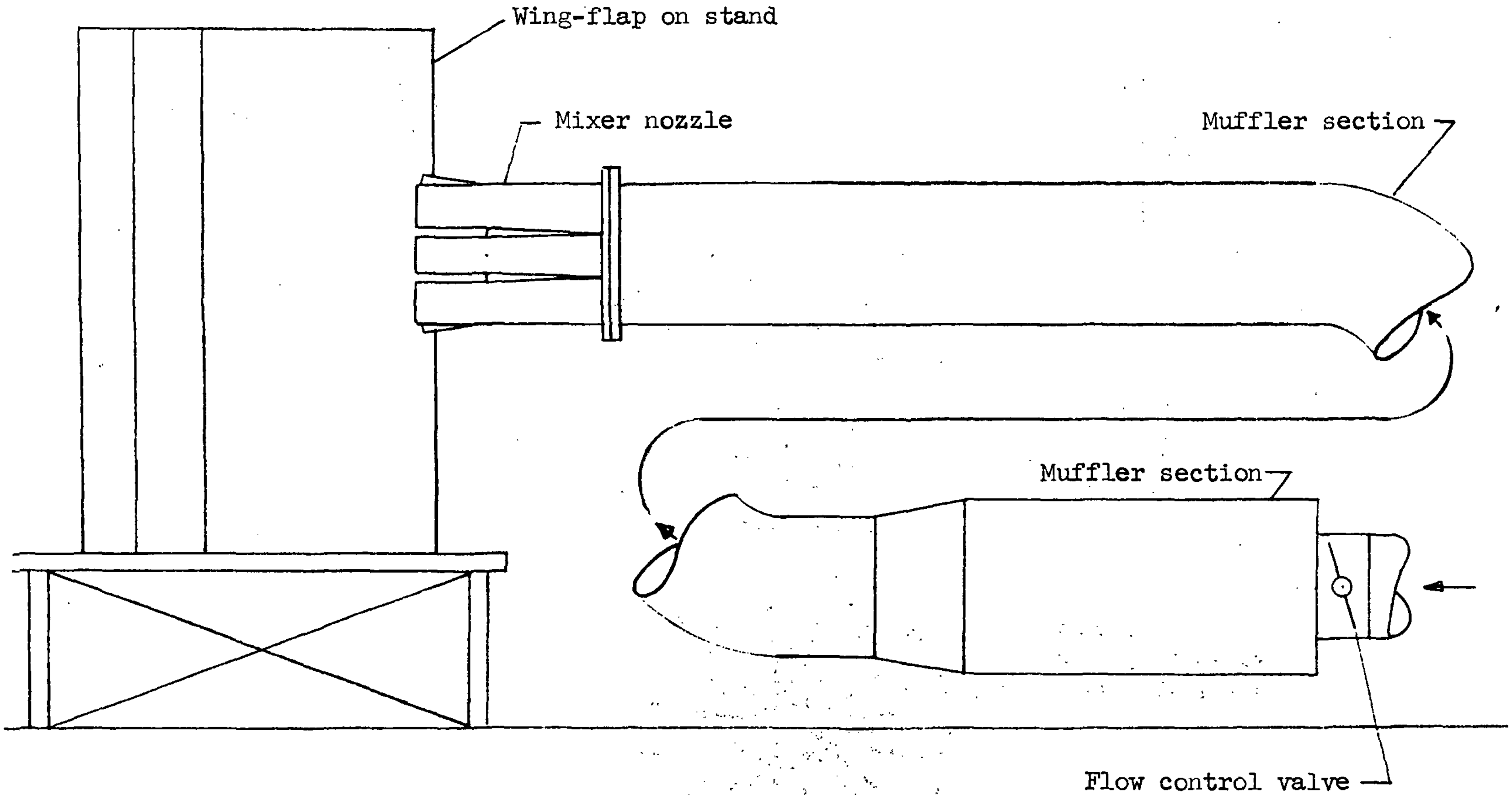


Figure 1. - Air flow system.

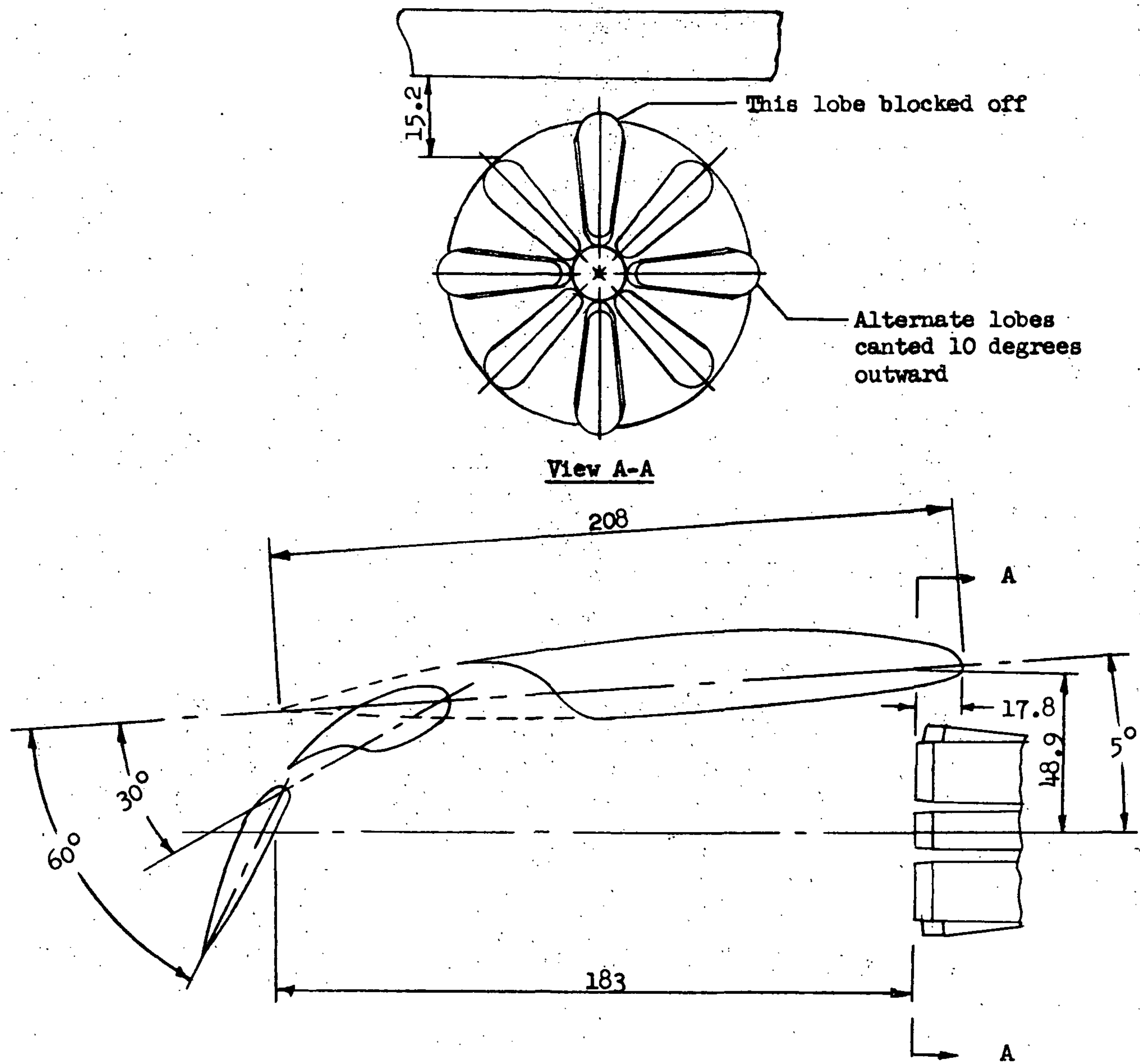


Figure 2. Test configuration of the externally blown flap model with the mixer nozzle (all dimensions in centimeters).

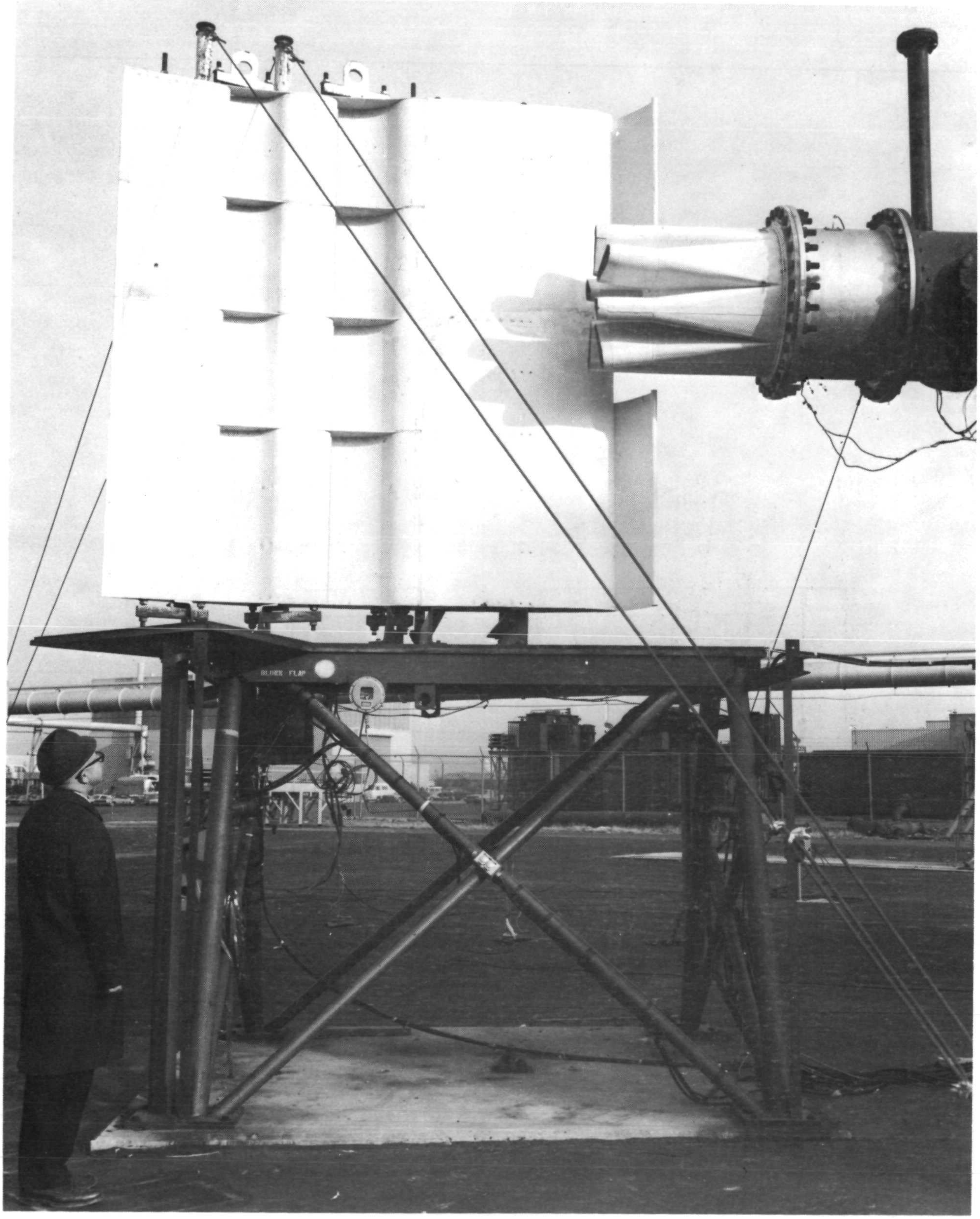


Figure 3. Externally-blown-flap model with research mixer nozzle.

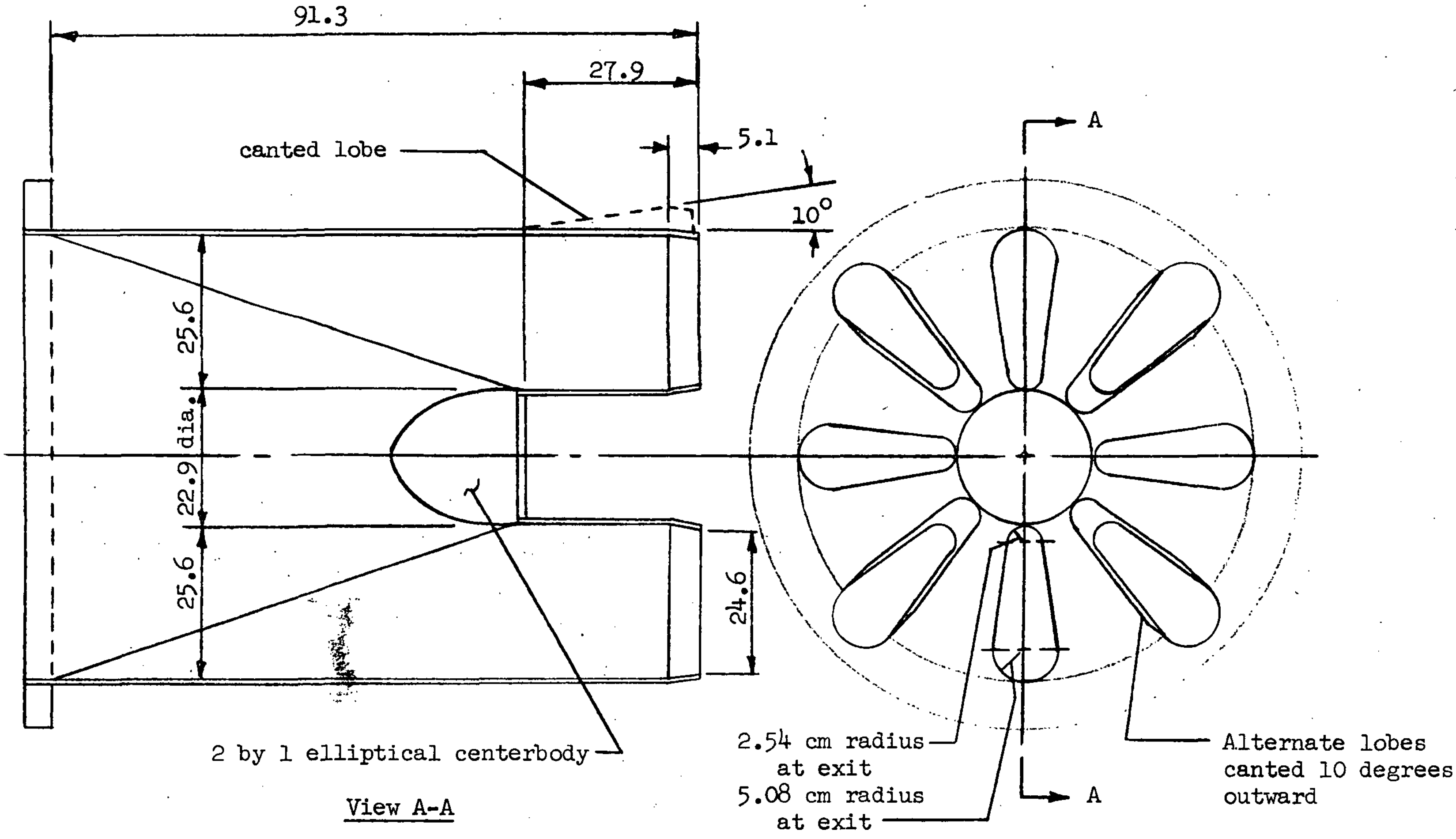


Figure 4. Configuration and dimensions of the mixer nozzle (all dimensions in centimeters).

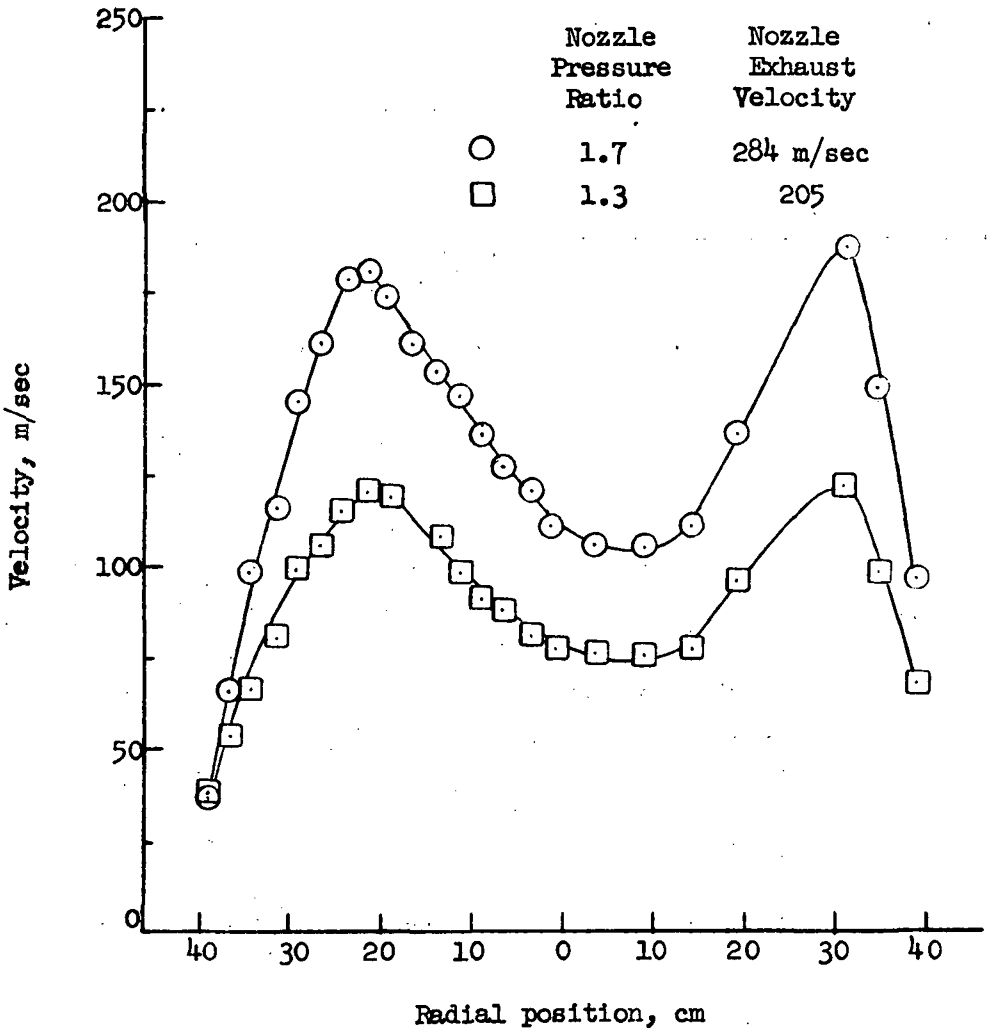


Figure 5. Velocity profiles across the straight lobes of the mixer nozzle at an axial distance of 183 cm downstream of the nozzle exit.

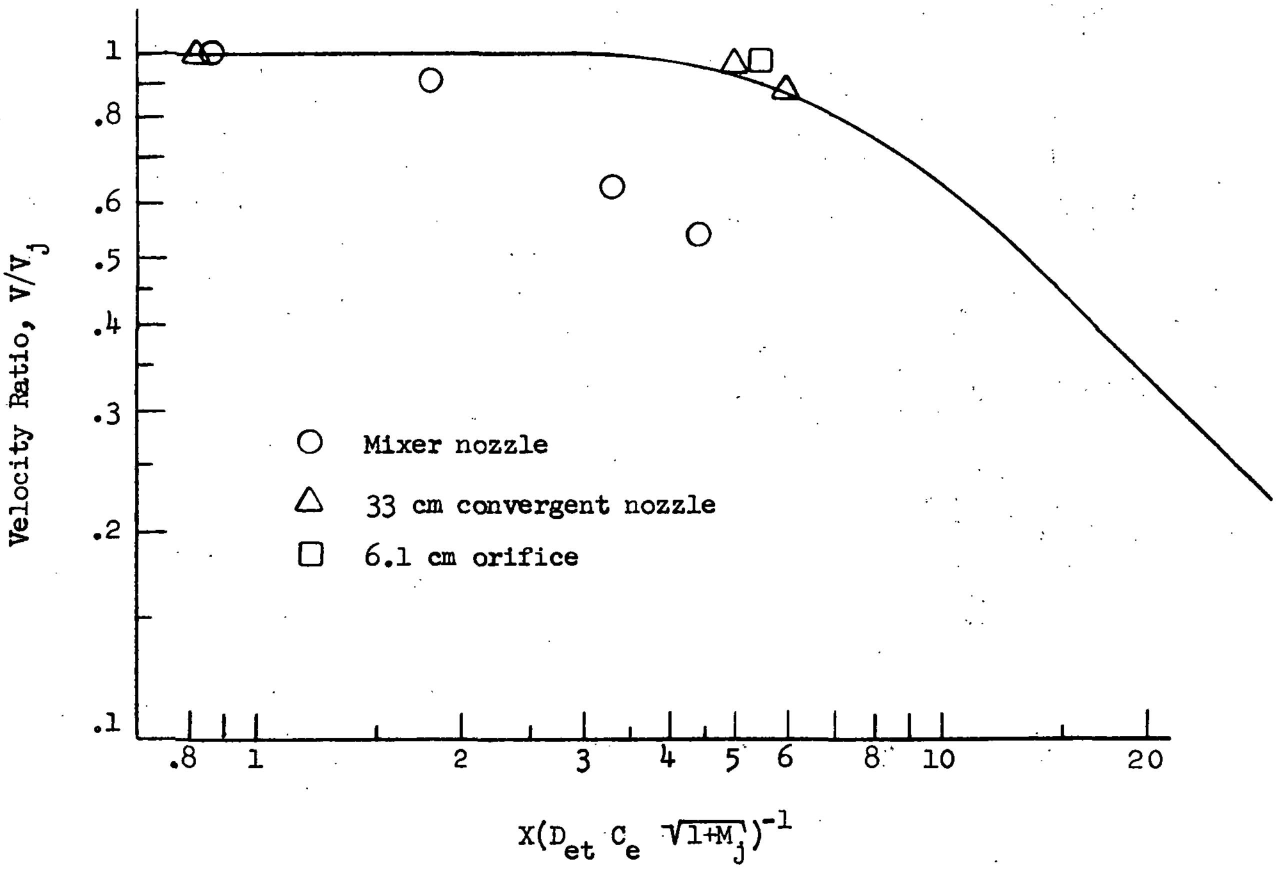
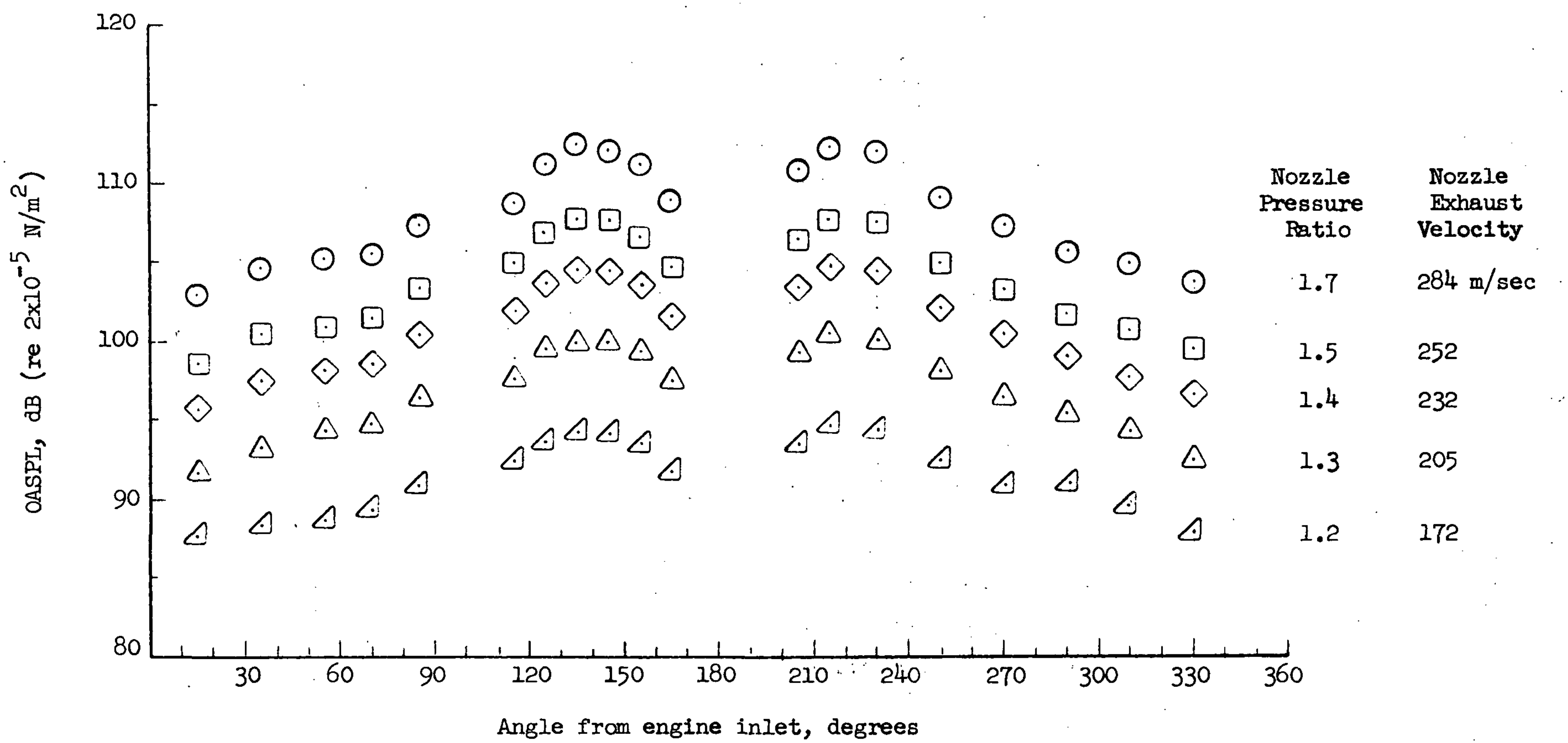
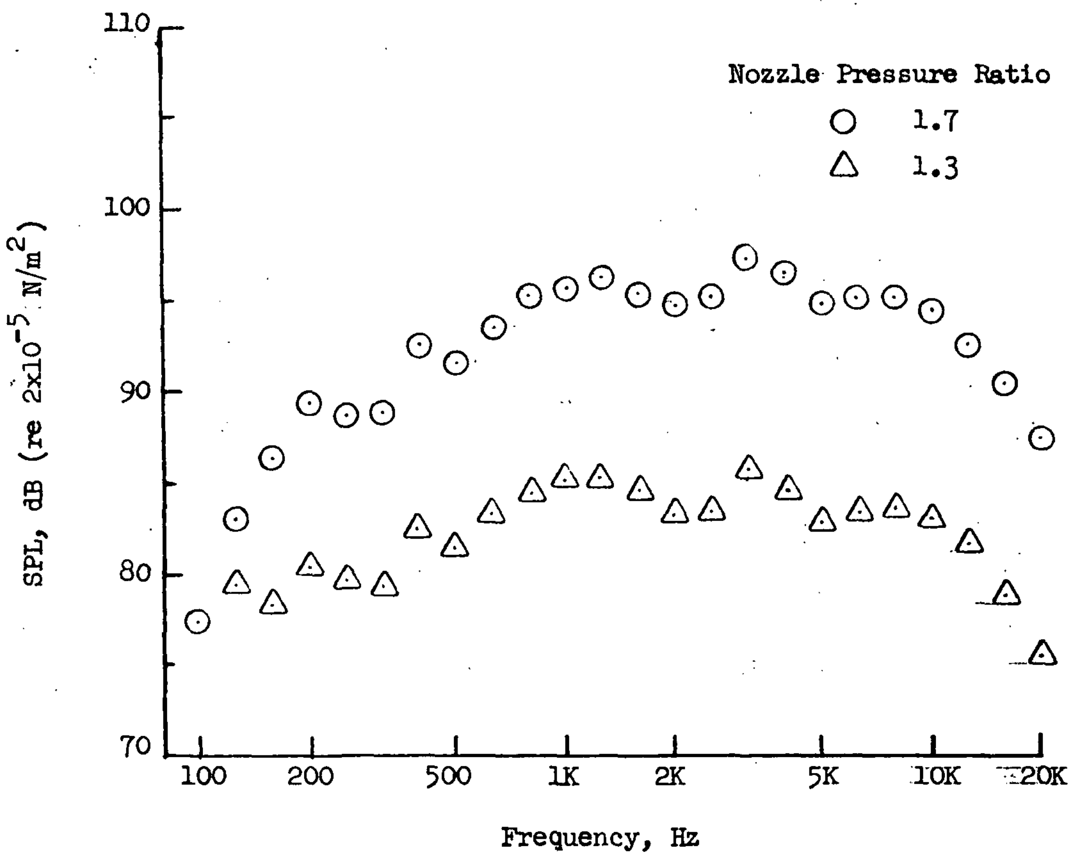


Figure 6. Comparison of velocity decay for single nozzles and mixer nozzles



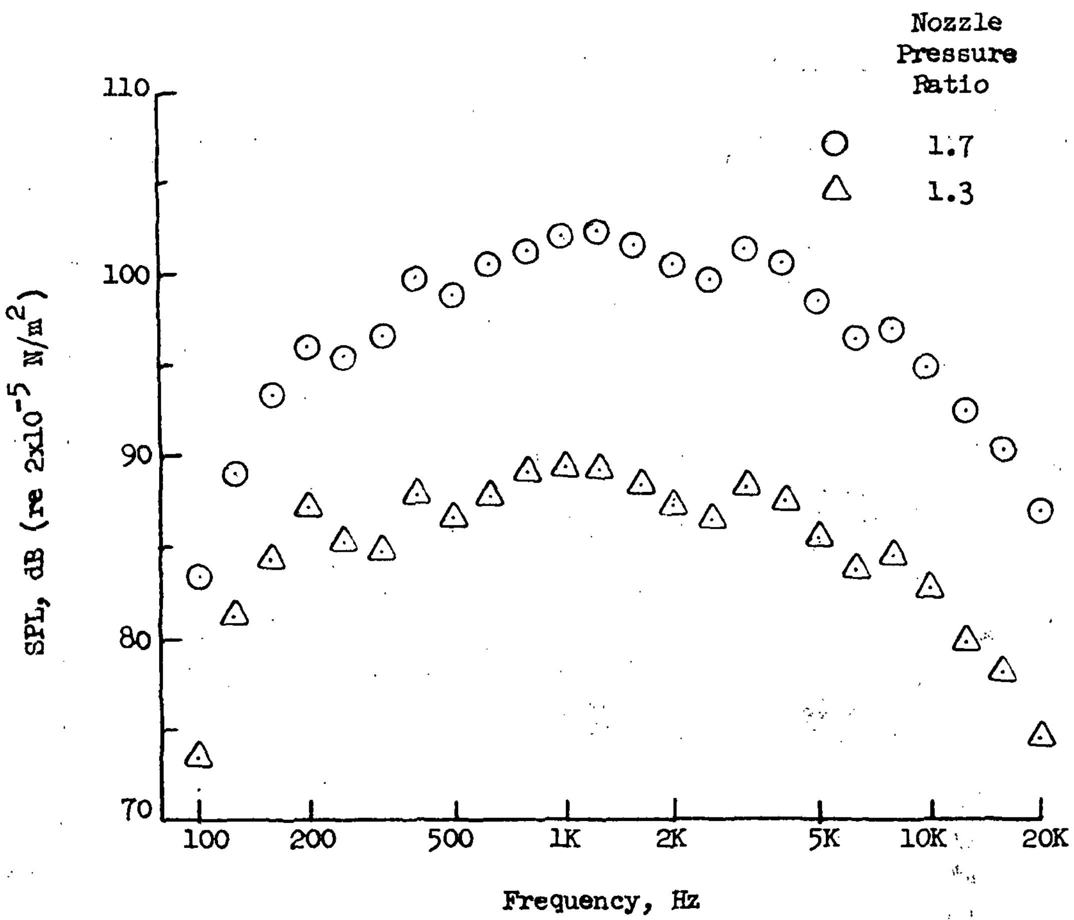
(a) Overall sound pressure level directivity

Figure 7. Comparison of noise data for the mixer nozzle alone at various nozzle pressure ratios.



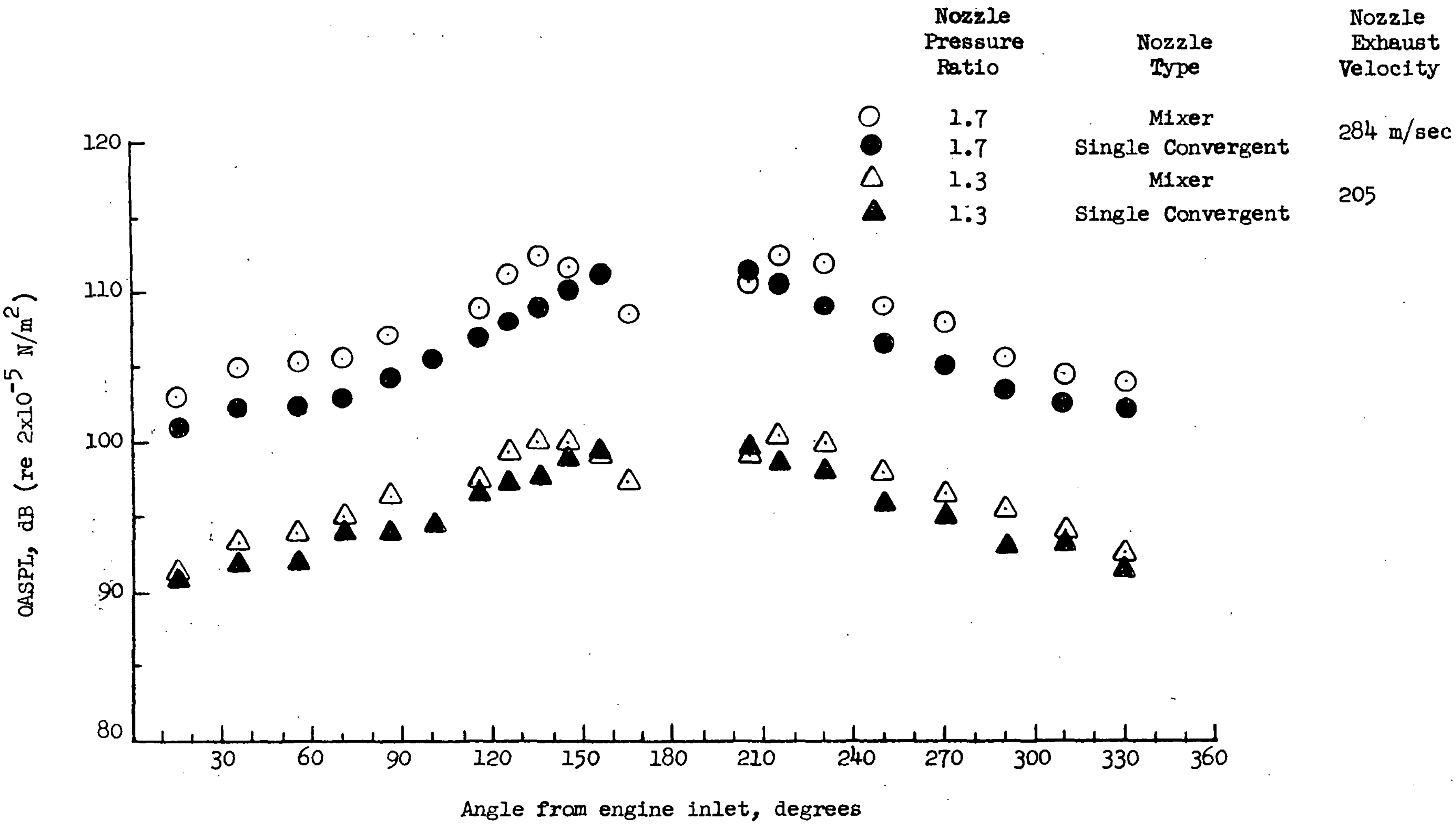
(b) SPL 1/3 octave spectra at 85°

Figure 7. Cont.



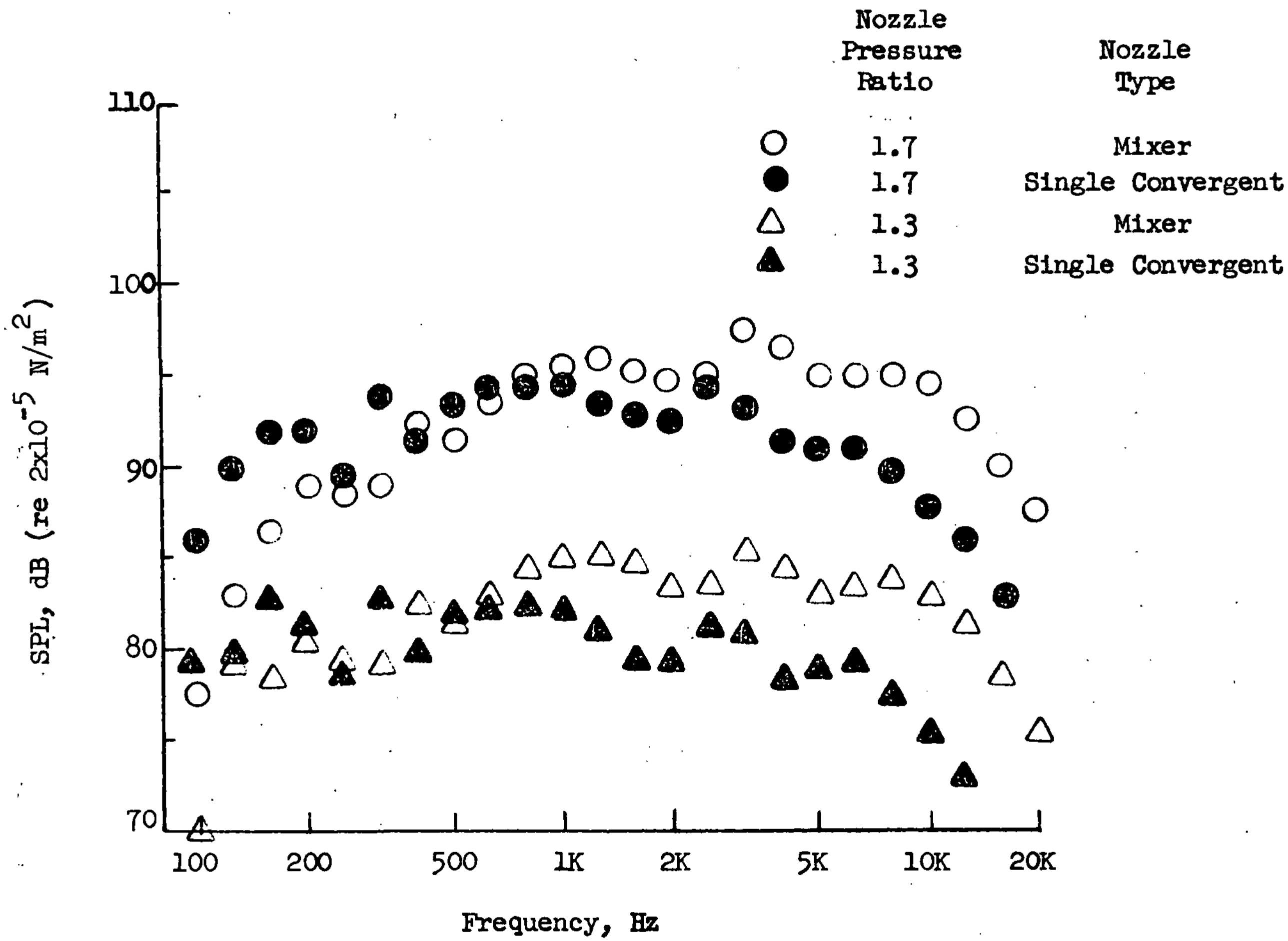
(c) SPL 1/3 octave spectra at 135°

Figure 7. Cont.



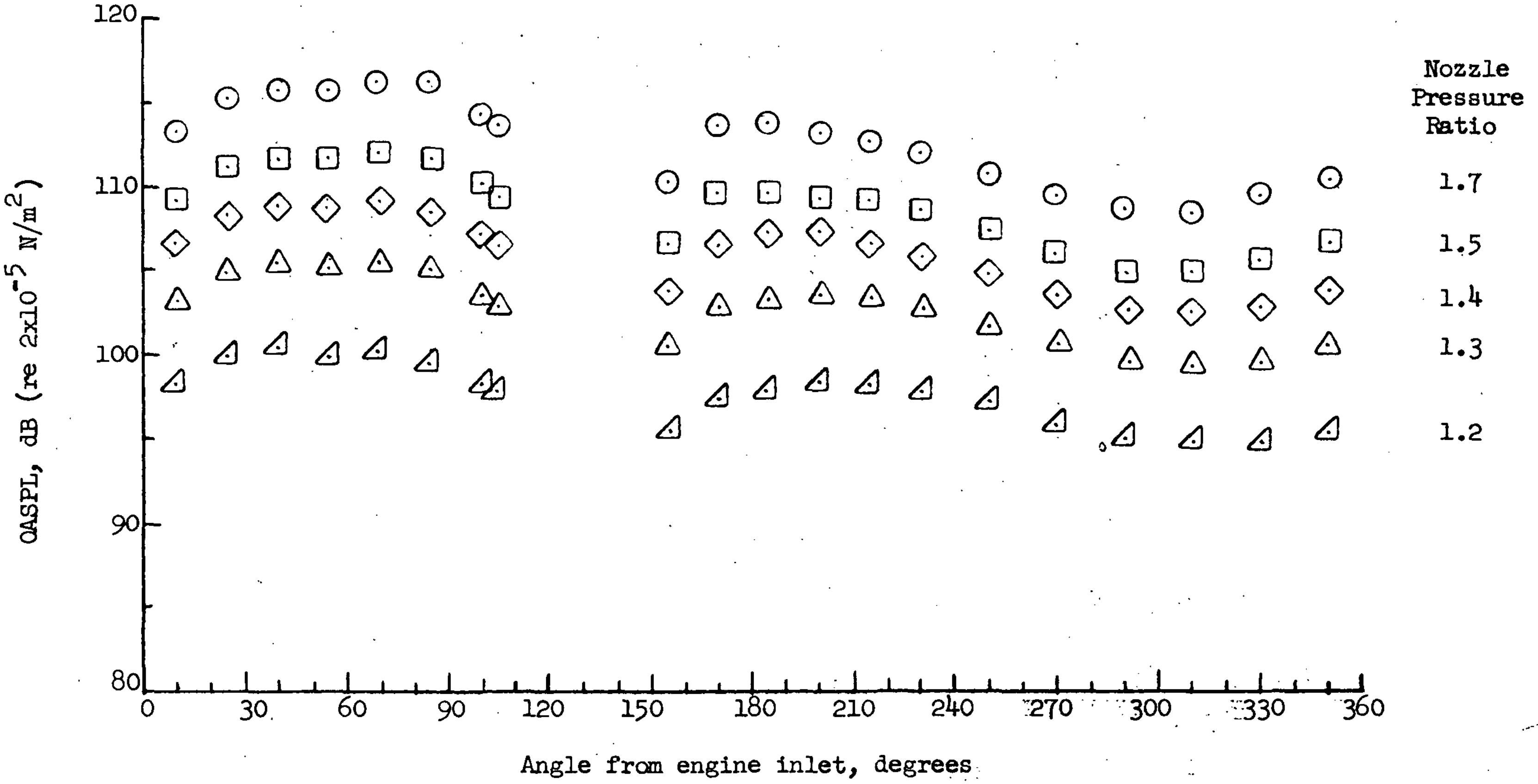
(a) Overall sound pressure level directivity

Figure 8. Comparison of noise data for the mixer nozzle alone and a 33 cm single convergent nozzle alone scaled up to the mixer nozzle.



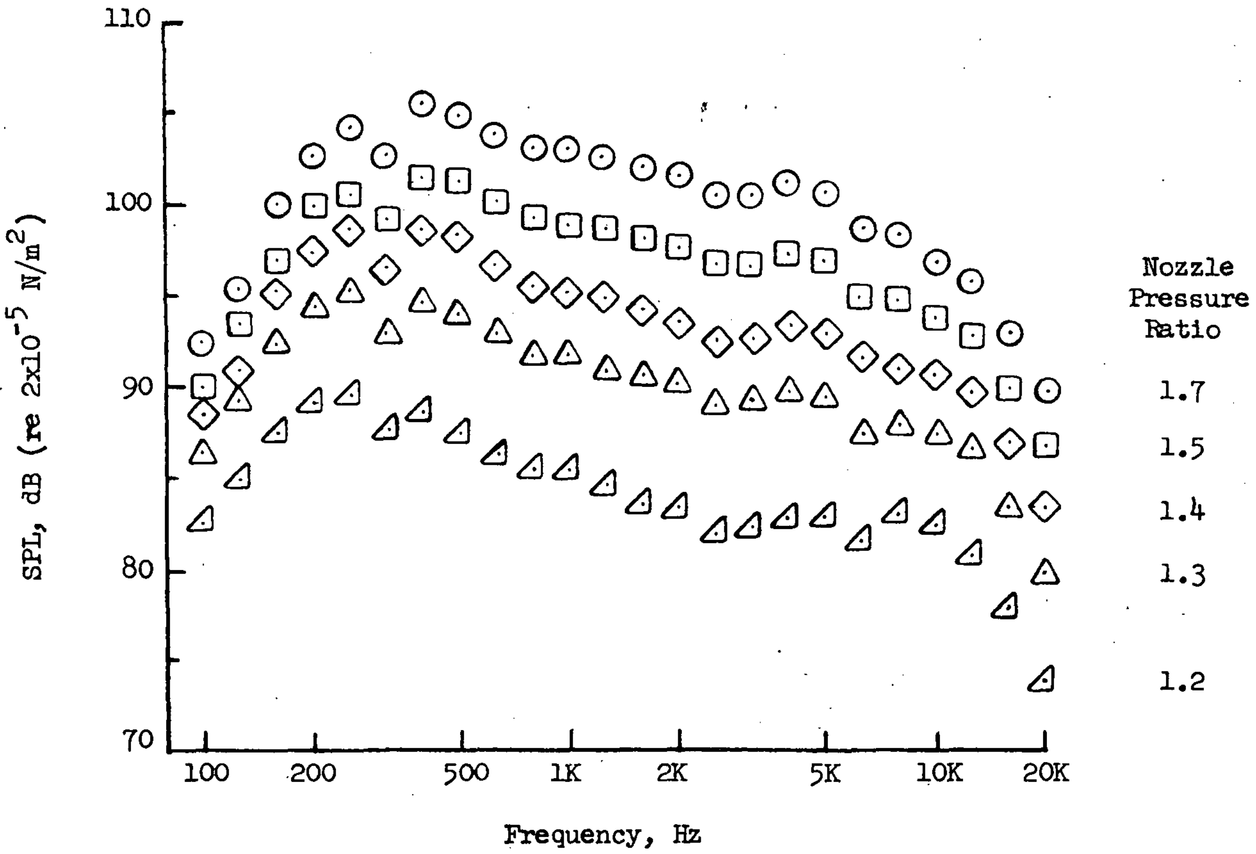
(b) SPL 1/3 octave spectra at 85°

Figure 8. Cont.



(a) Overall sound pressure level directivity

Figure 9. Comparison of noise data for the mixer nozzle with the 30°-60° flaps at various nozzle pressure ratios.



(b) SPL 1/3 octave spectra at 85°

Figure 9. Cont.

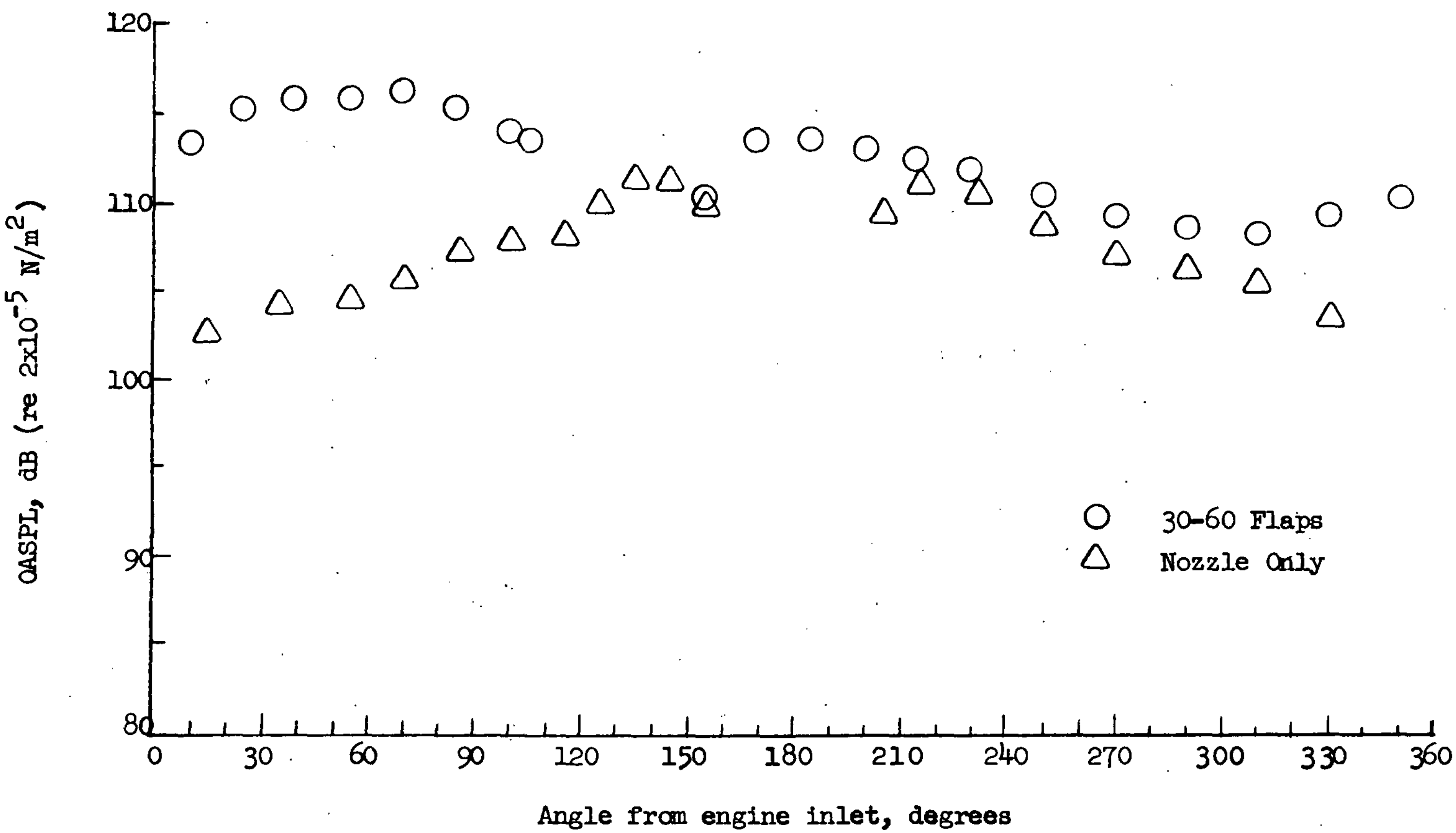
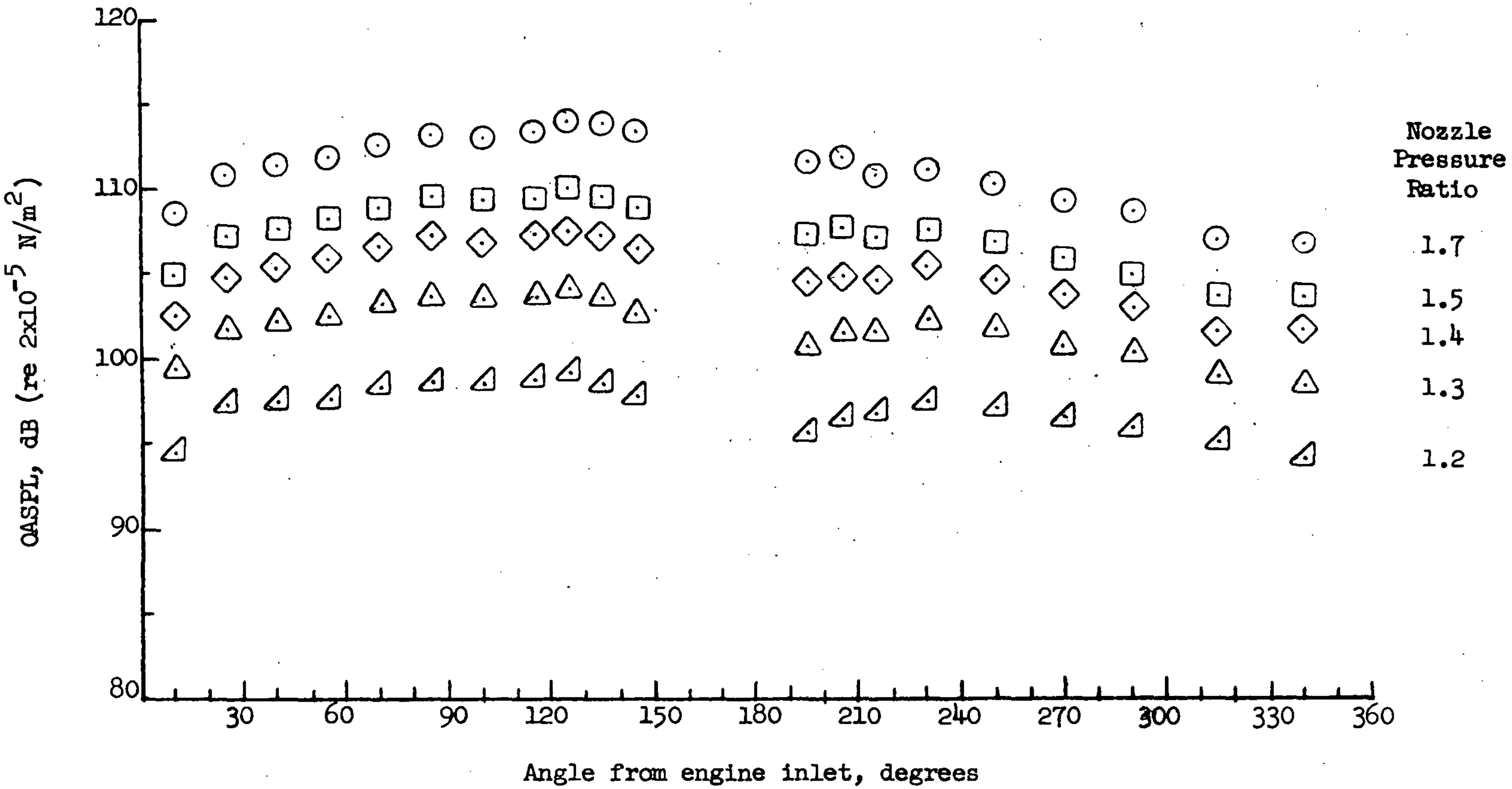
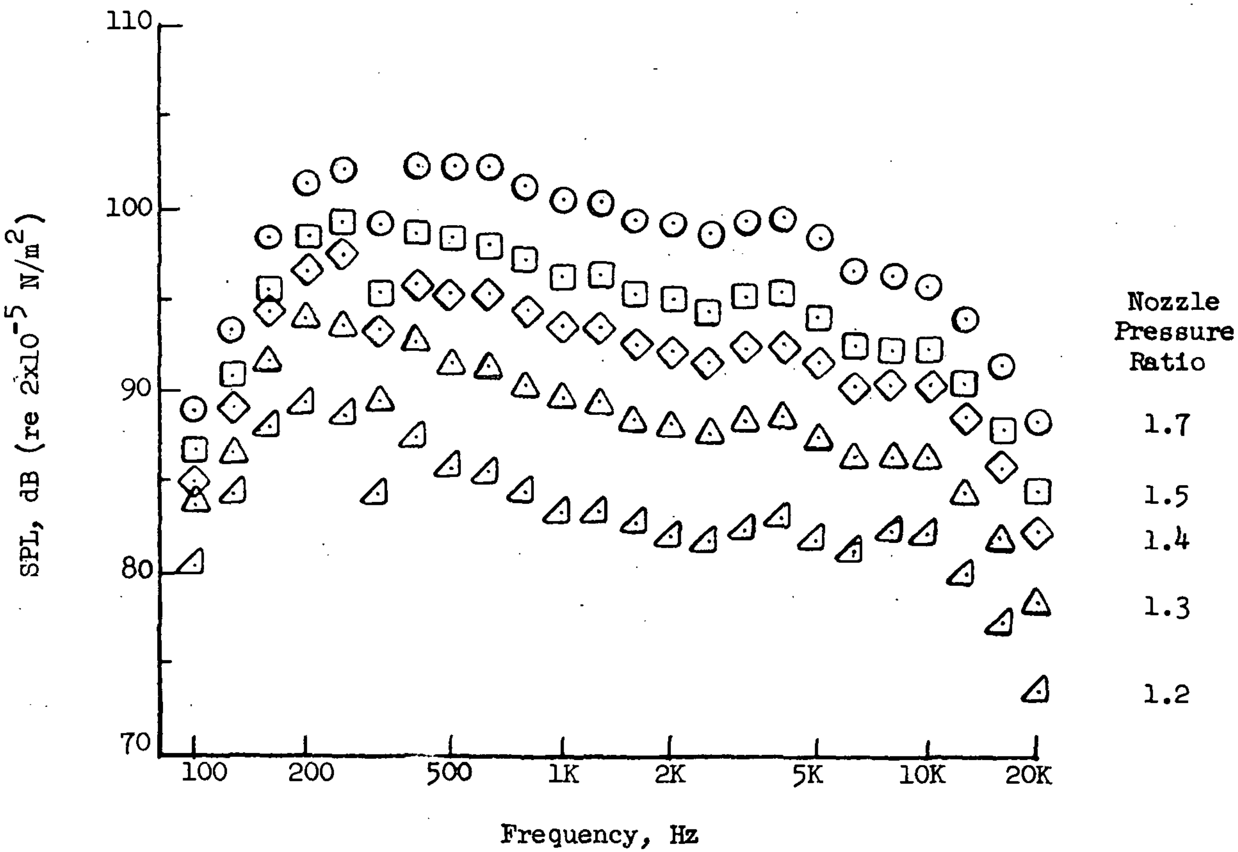


Figure 10. Comparison of noise data for the mixer nozzle with 30°-60° flaps and mixer nozzle only. Nozzle pressure ratio 1.7; nozzle exhaust velocity 284 m/sec.



(a) Overall sound pressure level directivity

Figure 11. Comparison of noise data for the mixer nozzle with the 10°-20° flaps at various nozzle pressure ratios.



(b) SPL 1/3 octave spectra at 85°

Figure 11. Cont.

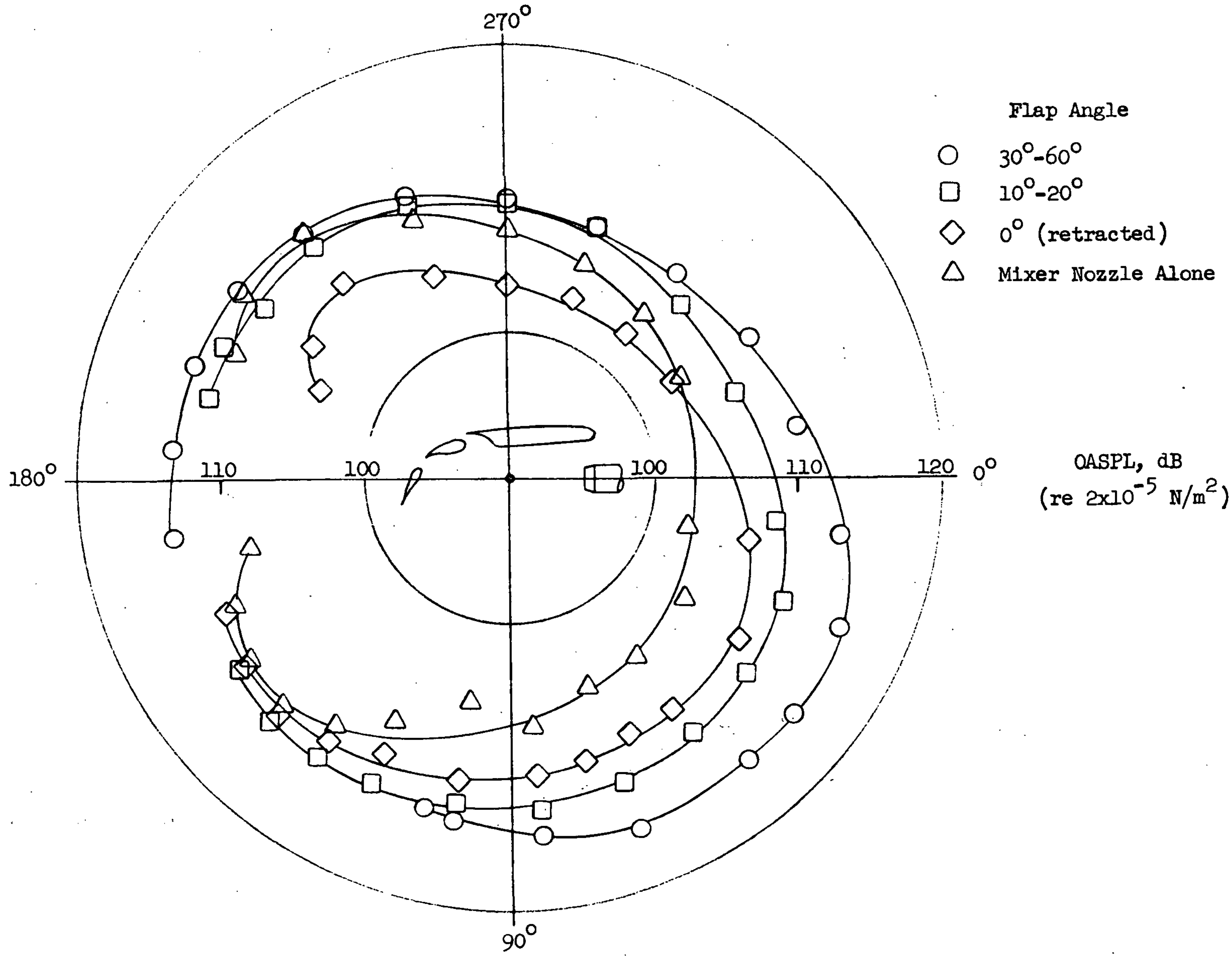


Figure 12. Comparison of noise radiation patterns for the mixer nozzle with various flap angles and the mixer nozzle alone. Nozzle pressure ratio, 1.7; nozzle exhaust velocity 284 m/sec.

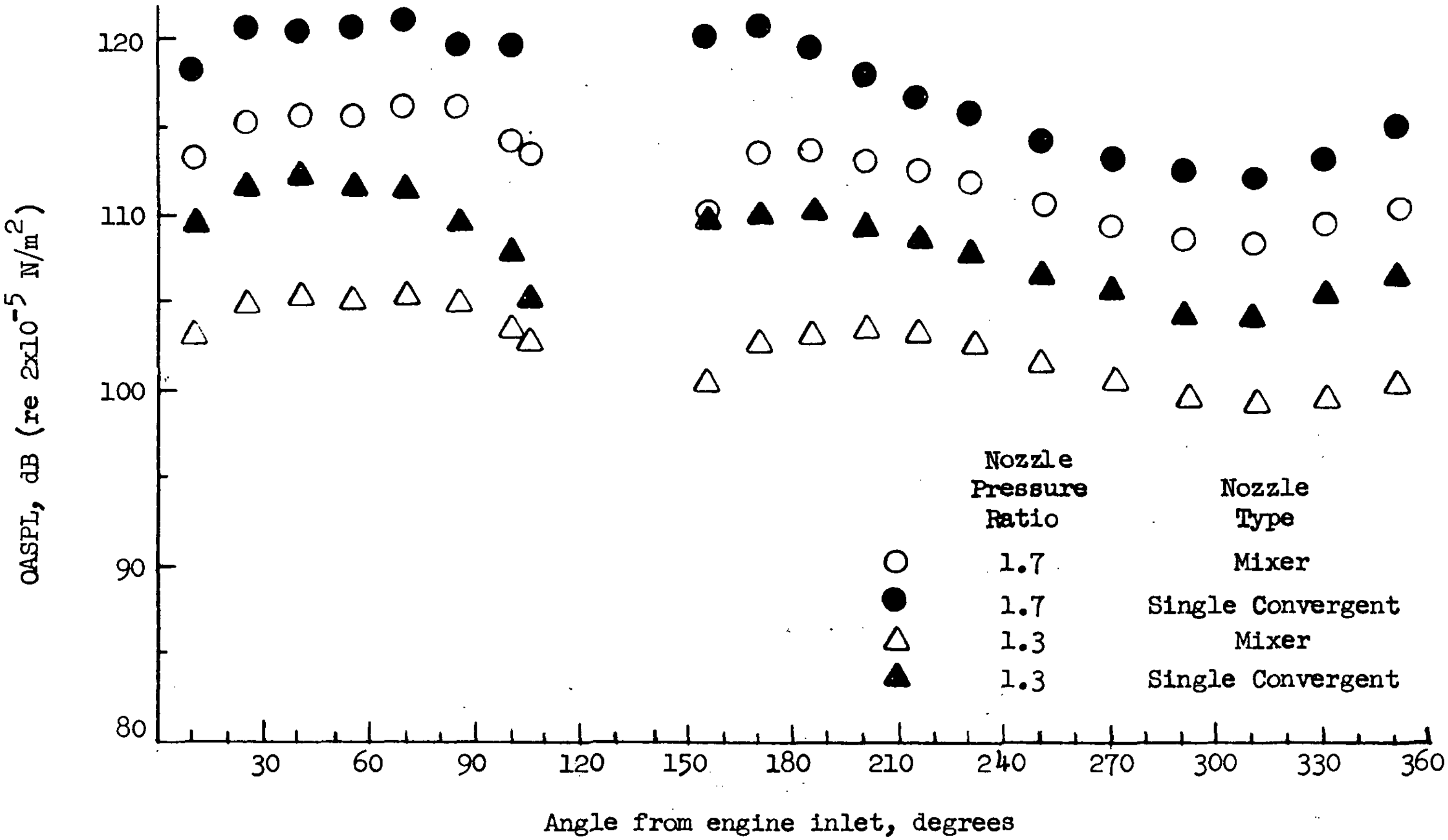


Figure 13. Comparison of noise data for the mixer nozzle with the 30°-60° flaps and a 33 cm single convergent nozzle with the 30°-60° flaps scaled up to the mixer nozzle.

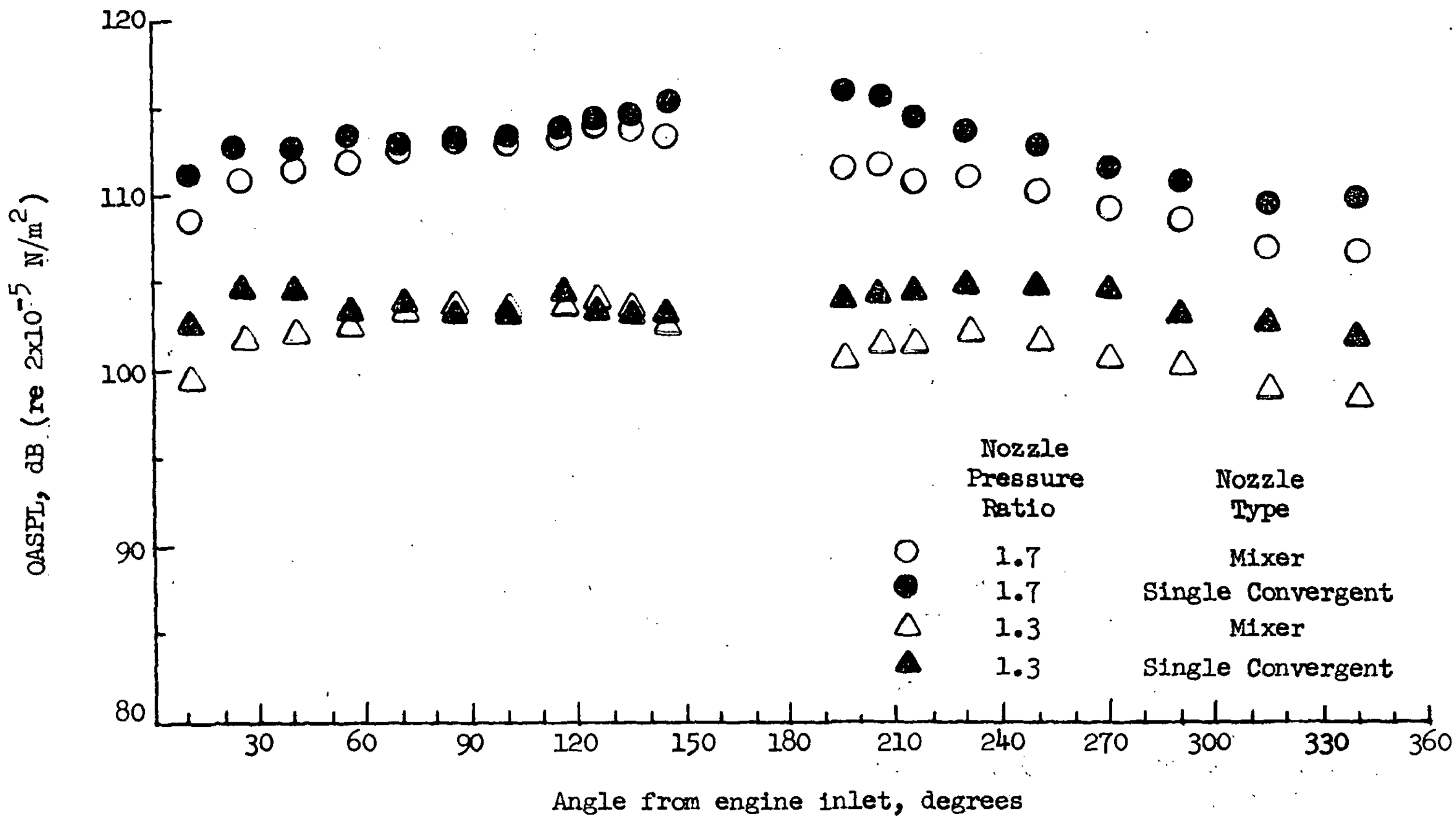


Figure 14. Comparison of noise data for the mixer nozzle with the 10°-20° flaps and a 33 cm convergent nozzle with the 10°-20° flaps scaled up to the mixer nozzle.

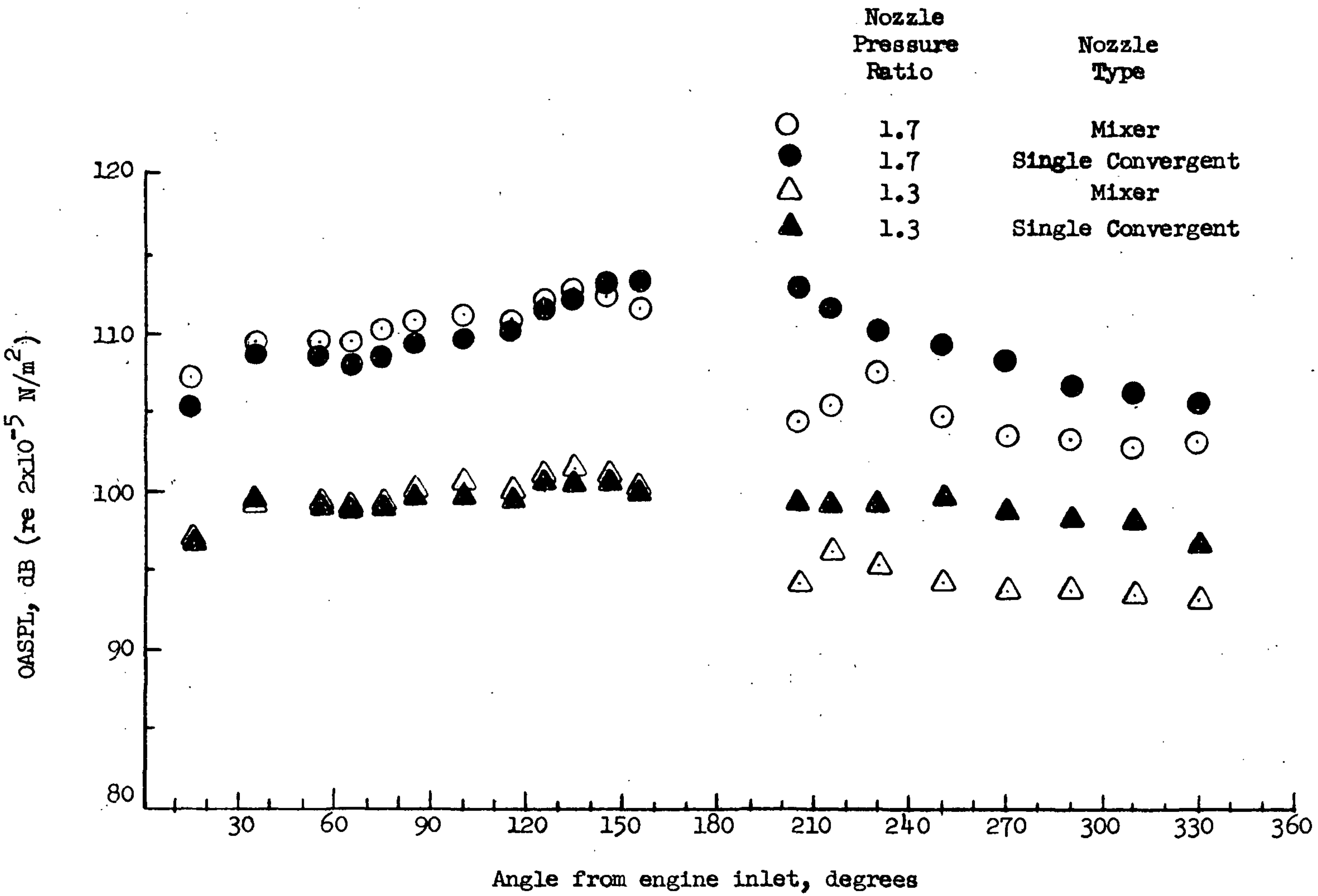
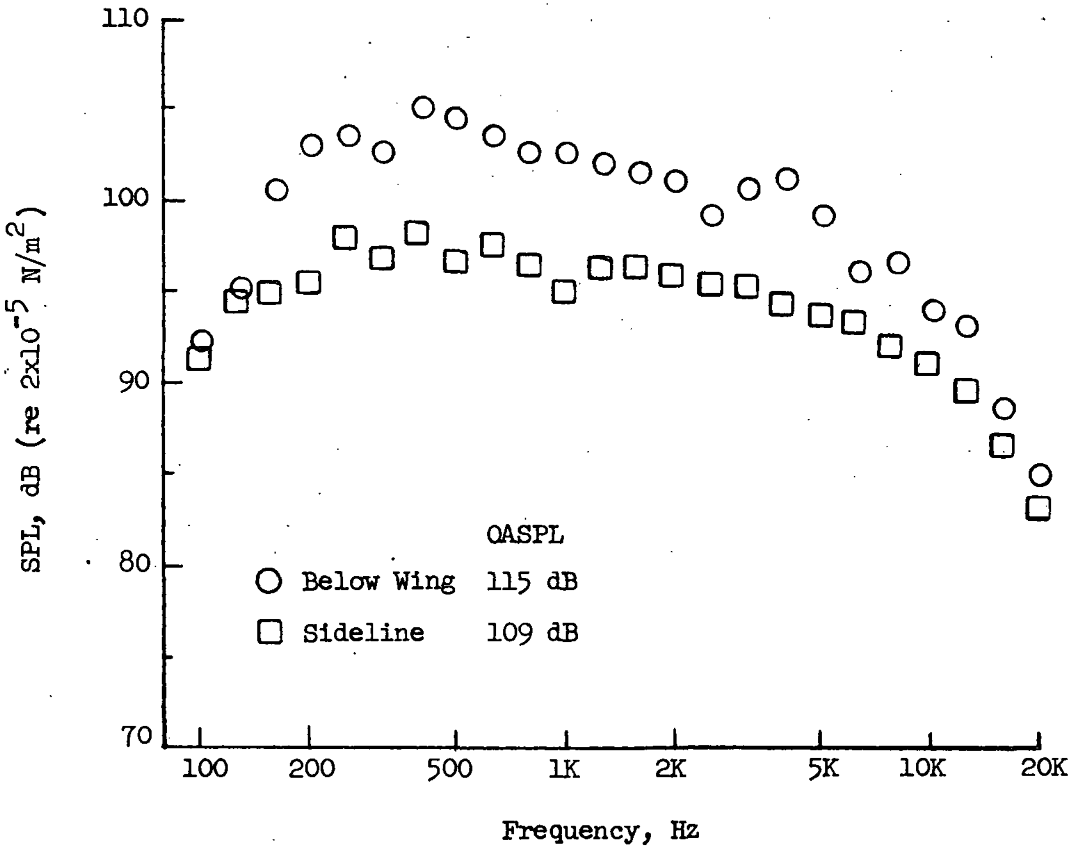
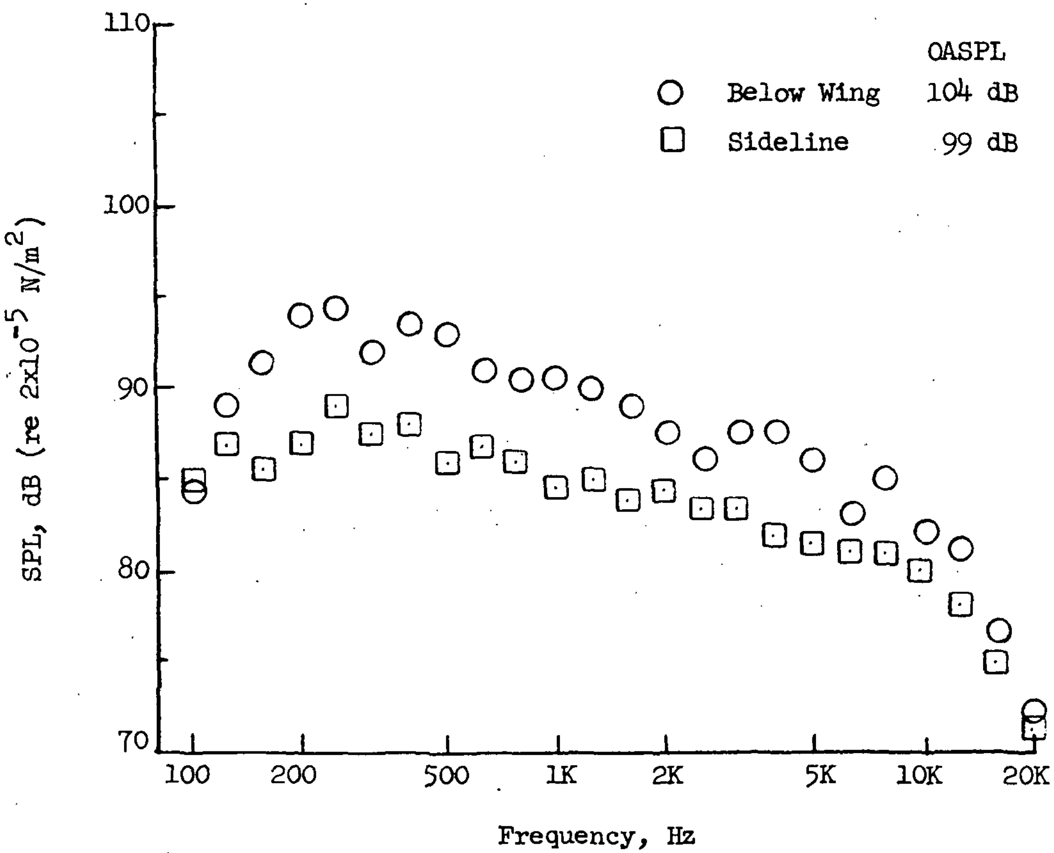


Figure 15. Comparison of noise data for the mixer nozzle with the zero flaps (retracted) and a 33 cm single convergent nozzle with the zero flaps scaled up to the mixer nozzle.



(a) Nozzle pressure ratio 1.7; nozzle exhaust velocity 284 m/sec

Figure 16. Comparison of SPL 1/3 octave spectra at 15.24 meters below the wing and 15.24 meters sideline distance with the mixer nozzle and 30°-60° flaps.



(b) Nozzle pressure ratio 1.3; nozzle exhaust velocity 205 m/sec

Figure 16. Cont.

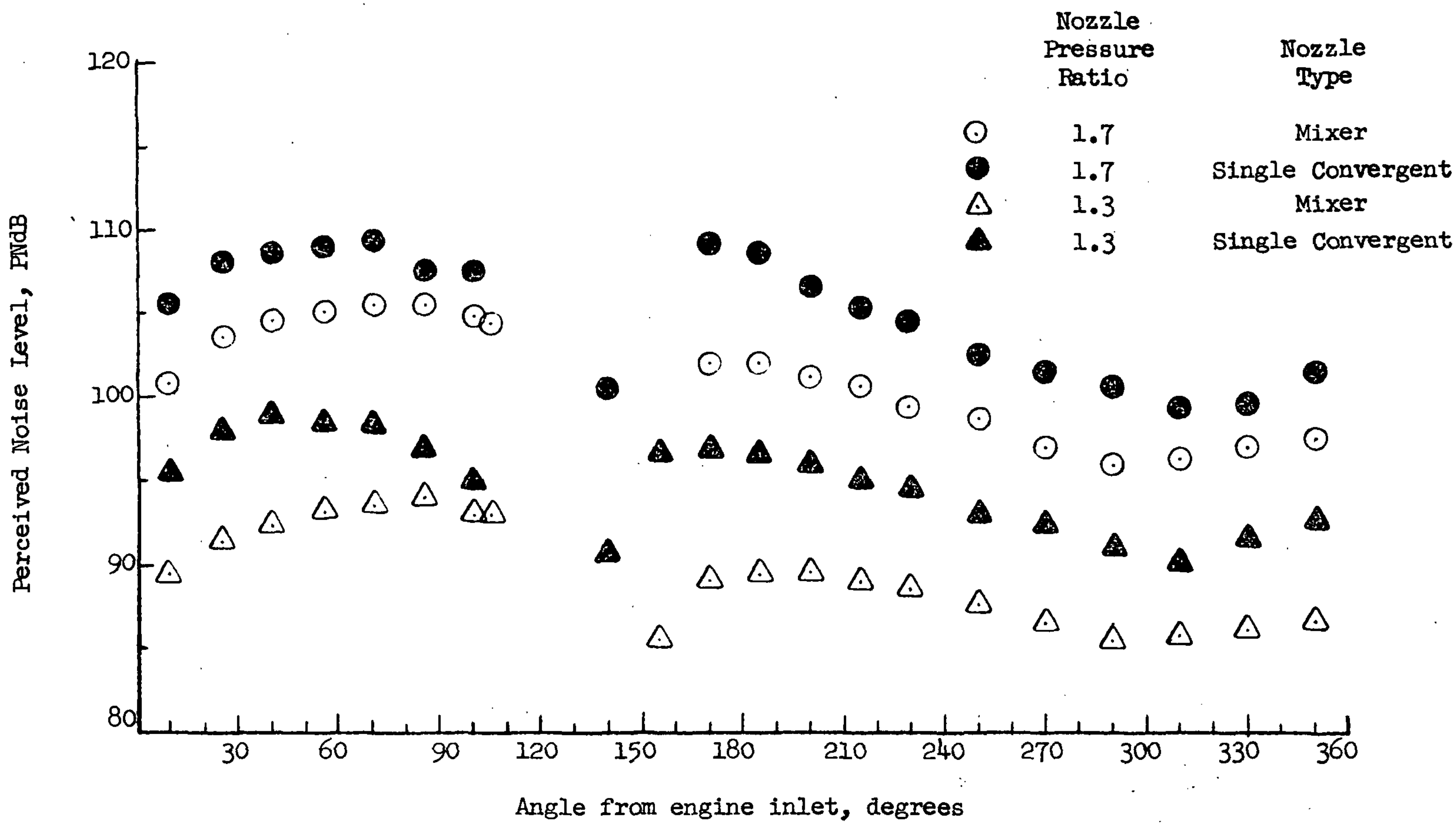


Figure 17. Comparison of perceived noise level directivity pattern at 152.4 meters for the mixer nozzle with 30°-60° flaps and a 33 cm single convergent nozzle with 30°-60° flaps scaled up to the mixer nozzle.

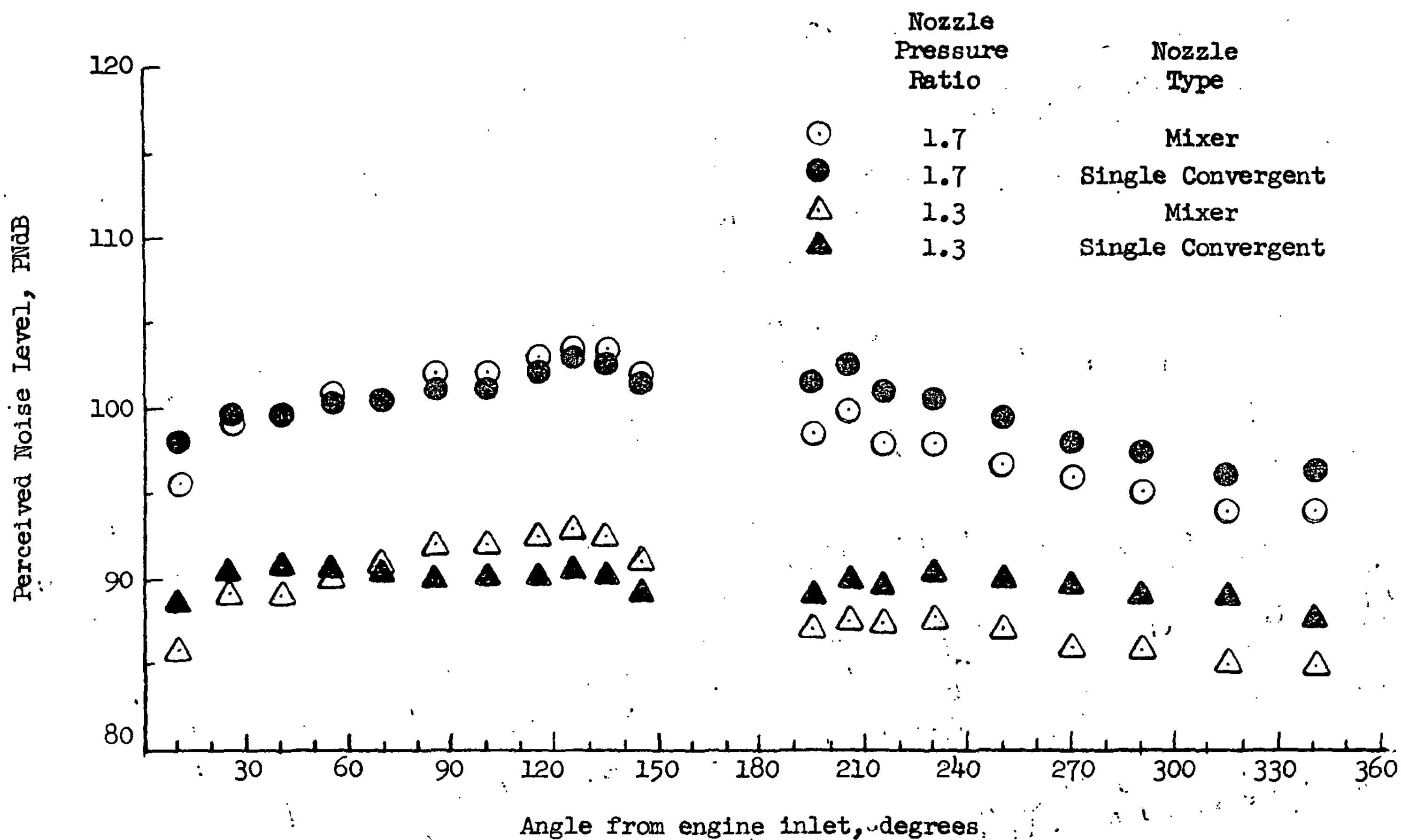


Figure 18. Comparison of perceived noise level directivity pattern at 152.4 meters for the mixer nozzle with the 10°-20° flaps and a 33 cm single convergent nozzle with 10°-20° flaps scaled up to the mixer nozzle.

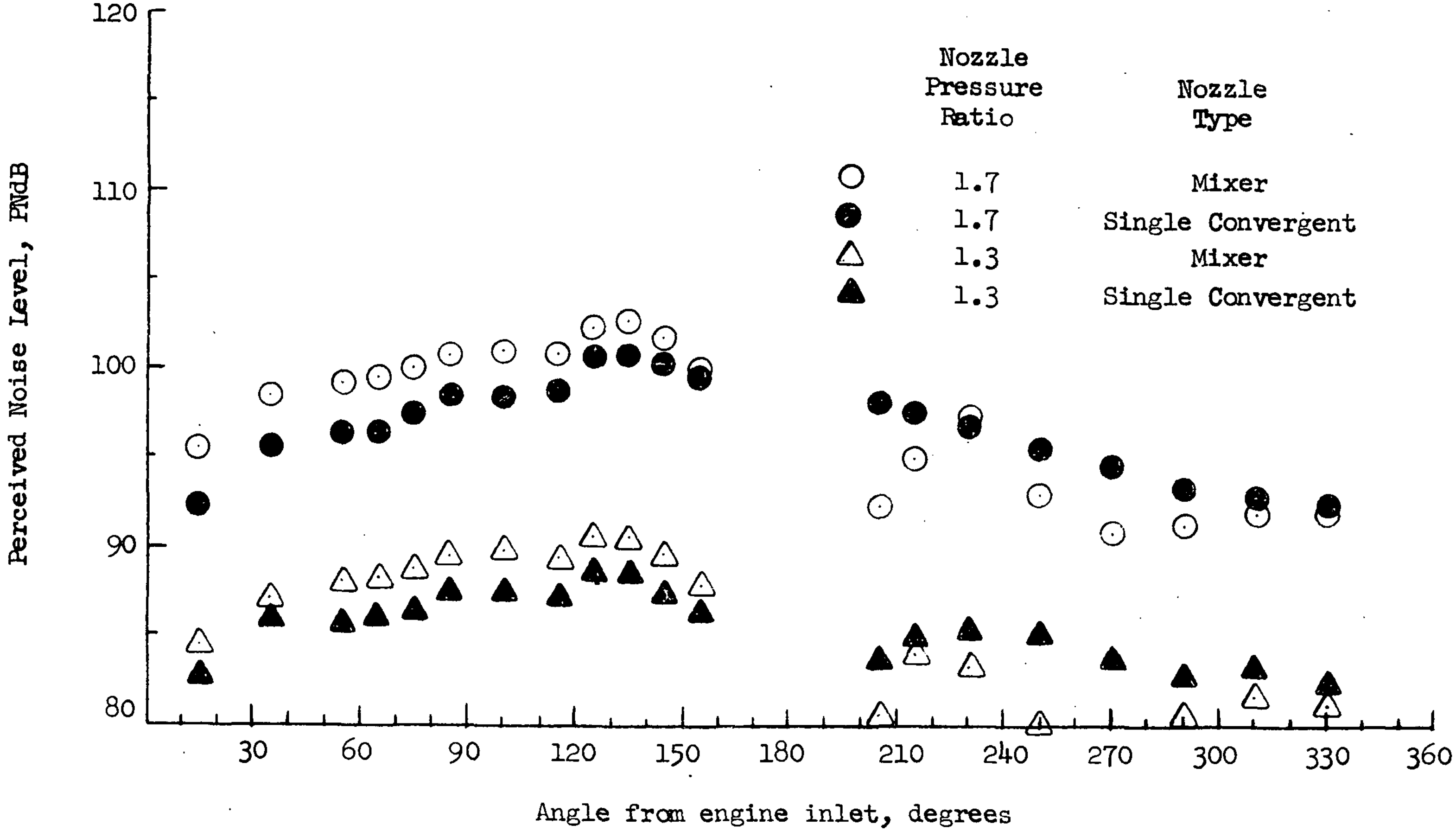


Figure 19. Comparison of perceived noise level directivity pattern at 152.4 meters for the mixer nozzle with the zero (retracted) flaps and a 33 cm single convergent nozzle with zero flaps scaled up to the mixer nozzle.